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THERMAL SENSATION: INFRARED AND MICROWAVES

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The number of studies of how microwaves arouse warmth sensations can be counted on the fingers of one hand. They leave many, many unanswered questions, but the nature of the questions to be asked will in general take shape in the light of the much larger amount of information that we have about the perception of infrared radiation. So the main substance of this paper is to use present knowledge to help formulate a hypothetical program of psychophysical experiments with microwaves that will take account of the main variables that determine the subjective response.

One important question concerns what levels of power density are needed to trigger a just-detectable sensation, i.e., what is the absolute threshold of warmth sensation for microwaves versus infrared radiation. We shall see below that this phrasing of the question is deceptively oversimplified. Nevertheless, we address first the question of how infrared and microwave thresholds compare when measured in the same subjects under comparable test procedures. Two studies give first-order answers to the question. Hendler, Hardy, and Murgatroyd (1963) compared thresholds of infrared and 3-cm microwaves for a 37 cm<sup>2</sup>, circular area of the forehead. Four subjects were tested by a variety of standard psychophysical procedures, including the classical methods of constant stimuli and limits. The threshold depended on the duration of the stimulation (the shorter the stimulation, the higher was the threshold). At all durations, however, the microwave thresholds were about twice as high as the infrared thresholds.

The second study (Justesen, Adair, Stevens, and Bruce-Wolfe, 1982) employed microwaves of 12.4 cm wavelength,

used a different psychophysical method, the double-staircase method (Cornsweet, 1962), and stimulated about 100 cm<sup>2</sup> of the forearm for 10 sec at a time. (Six subjects were tested with microwaves, but because of constraints of time only four of these same subjects were tested with infrared.) On the average the 12.4-cm microwave stimulation yielded thresholds that were about 15 times higher than the infrared thresholds. Hence there seems little doubt that the warmth threshold is inversely related to the penetration depth of the radiation.

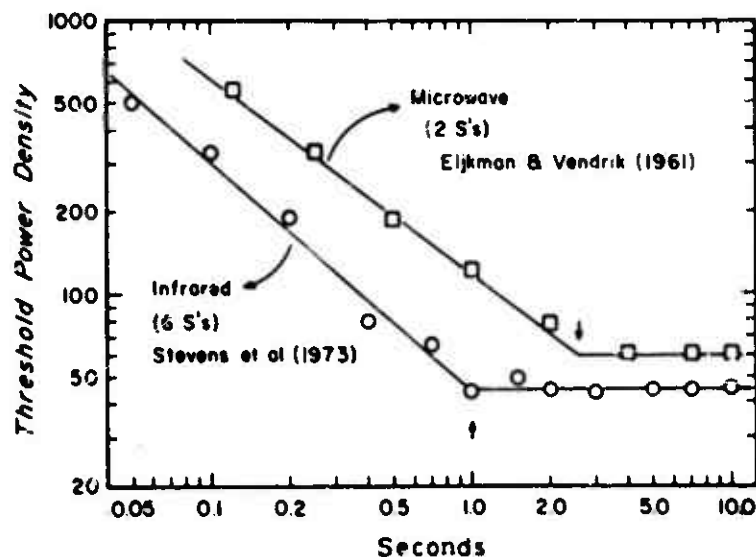


Figure 1. Relative threshold power density as a function of stimulus duration, comparing microwave and infrared stimulation. The relative up-down positions of the two functions is arbitrary because of the author's uncertainty of the absolute power density levels employed in Eijkman and Vendrik's study. However, the points illustrated here have to do with the relative shapes of the two functions, and it is known from other studies (see text) that microwaves yield higher thresholds than infrared.

One cannot stress too much that the understanding of the perception of radiation of any kind is not simply a matter of what level of stimulation a person can feel. The picture

is far more complicated, and my main interest in the paper is to try to convey something of this complexity. Consider, for example, Figure 1 which compared threshold measurements of infrared by Stevens, Oculicz, and Marks (1973) with threshold measurements of 10-cm microwaves by Eijkman and Vendrik (1961). The abscissa is the duration of the stimulus, and the ordinate is the relative power density needed to arouse a just-detectable sensation. The absolute up-down position of the microwave function I was unable to determine with certainty, but the studies just detailed above suggest that infrared produces lower thresholds than microwaves.

There are two noteworthy features illustrated by the figure. First, the threshold of power density depends on the duration of stimulation, almost (but not quite) by a reciprocity (power density counts slightly more, proportionally, than does duration). This phenomenon is called *temporal summation*, a psychophysical property exhibited by most of the human senses. However, this near complete reciprocity comes rather abruptly to a halt at a critical duration beyond which duration no longer matters. This is in itself remarkable because the skin temperature continues to rise beyond the critical duration. A second noteworthy feature is the difference in critical duration -- about 1 sec for infrared and 2.5 sec for microwaves. It will be interesting to see whether this difference holds with more extensive testing and whether critical duration varies systematically with wavelength. But to return to the main point: whether or not one detects radiation depends nearly as much on duration as on power density. We shall see later that the same statement could be made of stimulus area, body region stimulated, conditions of adaptation, and in all likelihood the wavelength of the radiation.

*Absolute thresholds* are only one way to examine the sensory effects of radiation. One might, for example, want to measure *difference thresholds* or what percentage increment to any given level of microwaves can be detected by the human observer. Analogous measurements made with infrared radiation by Herget, Granath, and Hardy (1941) showed that just-noticeably to increase a warmth sensation requires roughly a 20% stimulus increment on the forehead.

Another question of interest is the relation between the magnitude of the sensation and the level of radiation and other variables. One way to assess this is to have subjects make numerical estimates of arrays of stimuli that vary in level, area, duration, etc. Below is given an explicit illustration of this method. Still other measures of sensory function concern the latency, both of onset and offset of sensation. Observations by Hendler, Hardy, and

Murgatroyd (1963), by Schwan, Anne, and Sher (1966) and by Justesen, et al. (1982) suggest that microwave sensations yield very long onset and offset times compared with infrared.

*Variables That Affect Temperature Sensation.* I wish now to review some of the parameters of stimulation that seem likely to play key roles in the study of microwave-induced sensation. One obvious variable is the wavelength of the radiation. Here we have only a little information. Vendrik and Vos (1958) reported that 10-cm waves required for sensation about 10 times the power density of non-penetrating infrared waves. The work on 12.4-cm waves (Justesen, et al., 1982) yielded a corresponding ratio of roughly 15. The less penetrating 3-cm waves used by Hendler, Hardy, and Murgatroyd (1963) required only about twice the levels of infrared.

I have already touched on another variable, namely duration, which we know counts heavily for both microwaves and infrared. However, the data in Figure 1 are restricted

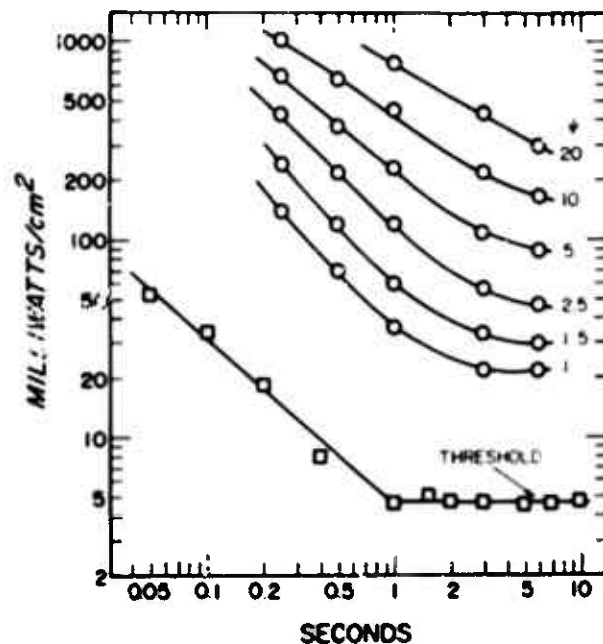


Figure 2. Showing the combinations of duration and power density (infrared) that produce a constant threshold and various constant warmth levels from weak to moderate.

solely to absolute thresholds, and it turns out that for infrared the rules of temporal summation change with increasing levels of warmth sensation. Figure 2 shows data of Marks and Stevens (1973). Each contour specifies the combinations of power density and duration that cause a constant warmth level. Although it is not so obvious to the naked eye, these contours tend to lose slope with increasing warmth level; that is, duration counts proportionally less and less than power density. On the other hand, the duration over which some summation can take place is extended to at least six seconds. Marks and Stevens argued that the heat transfer properties of the skin can basically explain the nature of this family of contours. Similar studies of microwaves could provide a rich source of information to test this theory further.

An even more important variable is the areal extent of stimulation. When a spot of radiation is enlarged one generally feels a greater degree of warmth level, not an increase in apparent area. This property is called *spatial summation*, and it is one of the most salient features of thermal sensation. In contrast, the sense of vision shows only trifling summation compared with warmth and cold. Changing the size of a spot of light typically leaves the brightness unchanged, and one sees instead simply an increase in the perceived area.

The rich summation of the thermal senses precludes good spatial acuity and localization of pure thermal sensations. Multiple spots of radiation usually fuse into a unitary sensation vaguely localized. Such fusion probably takes place in the central nervous system because two spots to the extreme sides of the forehead, for example, fuse to a single sensation vaguely localized near the midline. Localization of single spots is characteristically poor. Cain (1973) found that people often even confuse stimulation of the front and back of the torso, the typical error rate running about 20%. One suspects that microwaves will prove at least as difficult to localize and discriminate spatially.

There are alternative ways to study spatial summation. The first real quantitative data were the threshold studies of Hardy and Oppel (1937), and these have been confirmed and extended by more recent investigations (Kenshalo, Dector, and Hamilton, 1967; Stevens, Marks and Simonson, 1974). These studies show that in all regions of the body, power density and area trade by a near reciprocity to produce a just-detectable sensation. The area of threshold summation may be as large as 60 cm<sup>2</sup> or more.

As was true for temporal summation, the rules of spatial summation change as the criterion warmth level changes from

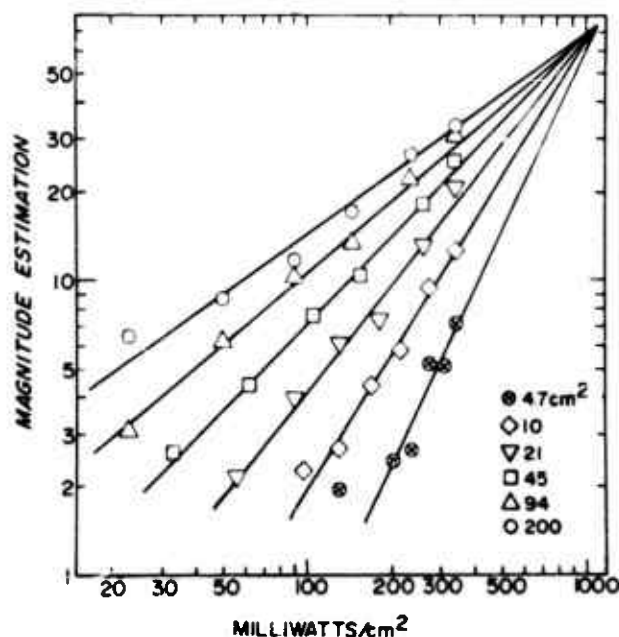


Figure 3. Magnitude estimation of warmth aroused by stimulating various areal extents of the back with various levels of infrared power density. This family of functions is fairly well described by straight lines in log-log coordinates, and they are therefore power functions of varying slopes.

a threshold sensation to a near painful level. Stevens, Marks, and Simonson (1974) studied these rules in several regions of the body. The procedure was to present various levels of radiation to various areal extents of the skin. In the course of testing, the subjects were generally unaware that area varied, and their instruction was simply to assign numbers to the apparent warmth level experienced in 3-sec exposures. This simple procedure generates data like those shown in Figure 3. Here one sees how apparent warmth level grows as a function of radiation level. There are four features to point out. (1) The thresholds for the small areas are high, but above threshold warmth grows fast with radiation level, i.e., the functions have steep slopes in log-log coordinates; (2) All of the functions converge at the threshold of thermal pain where there is no spatial summation; (3) For any given radiation level, the greater the area the greater the warmth experienced; (4) By making a

horizontal cross-section through these functions one can specify the various combinations of level and area that produce the same apparent warmth levels; in other words, one can use this figure to generate trade-off functions for area and level.

Figure 4 shows some typical trade-off contours for the back. We see here that at low warmth levels the trade-off is a near-reciprocity. With increasing level, power-density comes to count more and more than area, although the area over which some summation can occur expands to include

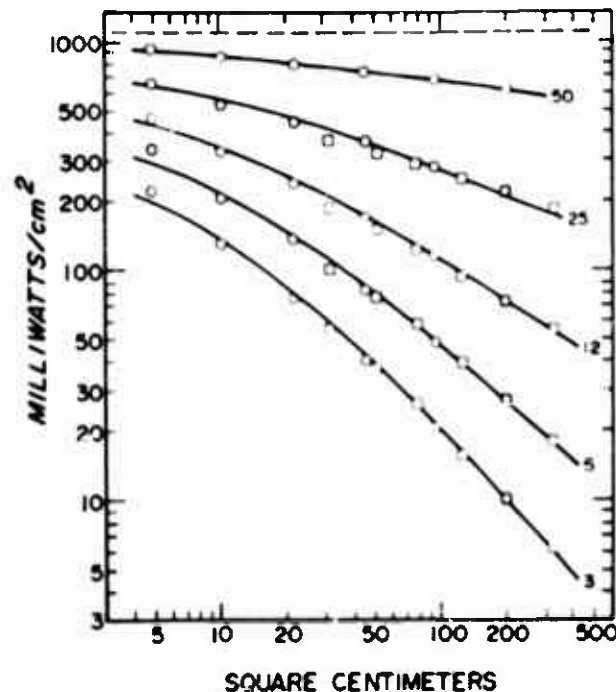


Figure 4. Showing the combinations of areal extent and infrared power density that produce various levels of constant warmth from weak (contour marked 3) to strong (contour marked 50). The dashed line represents the approximate thermal pain threshold for 3-sec exposures. The squares were generated from the data in Figure 4, the circles from an earlier similar study by Stevens and Marks (1971) done at a different time of year.

virtually the whole back of the torso. At the pain threshold, spatial summation ceases and localization improves. There is little question that spatial summation will also characterize microwave sensations, so one must be on guard against talking about a power density threshold, for example.

Body region also counts. Figure 5 shows the level of infrared necessary to produce various levels of warmth sensation from weak to strong (Stevens, Marks, and Simonson, 1974). At low levels the face is the most sensitive region, the trunk intermediate, and the limbs least sensitive. However, the regions become more uniformly sensitive at higher warmth levels. Very likely microwaves would also reflect these regional differences.

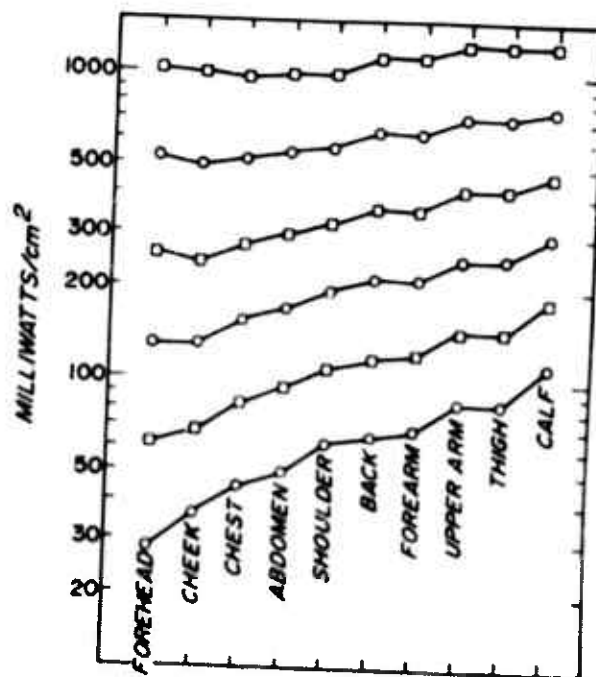


Figure 5. Showing the infrared power density needed to arouse the same warmth levels in ten regions of the skin. The contours become flatter as criterion warmth varies from weak to painful.



This listing of relevant parameters is not meant to be exhaustive. I have, for example, confined myself to studies using relatively transient stimulation and thereby avoided the complexities of thermal adaptation. It is commonplace in thermal psychophysics, however, that sensations aroused by infrared stimulation or by contact stimulation tend to fade over time. There is every reason to think that microwave-induced sensations will do the same. In fact, Justesen, et al. (1982) made some casual observations that resembled adaptation. The problem of adaptation may turn out to have a central role in understanding the behavior of organisms exposed to microwave radiation over long periods of time. I have also left out of discussion potential personal variables such as age, sex, and body dimensions. Finally, I have said nothing about the arousal of pain by microwave stimulation. Cook (1952) measured pain thresholds, and again the picture appears complex in that

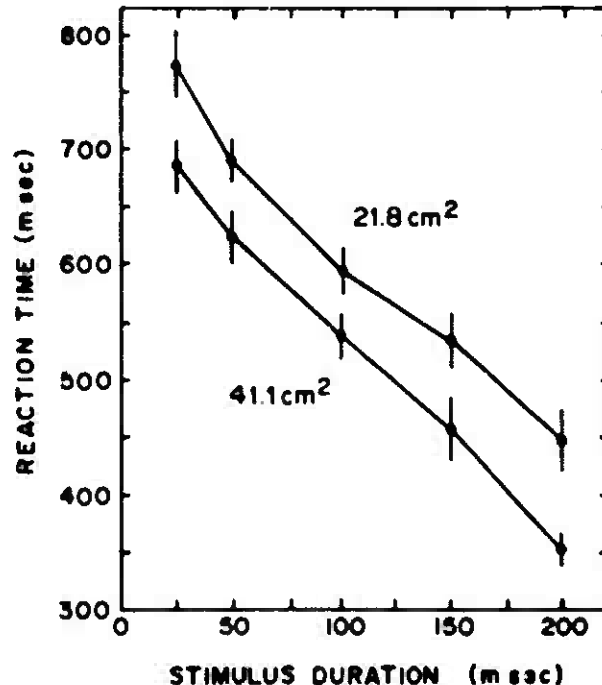


Figure 6. Showing how the reaction time for a constant power density (infrared) varies as a function of five different durations and two areal extents of the forehead. Redrawn from Banks, 1976.

the threshold depends not only on power density, but also on duration and area of exposure.

In conclusion, one must emphasize that the three most potent variables governing warmth sensation appear to be power density, area, and duration. These three can be traded one for another to produce a given sensory effect. As a final example, in Figure 6 we see data of W. P. Banks (1976) showing that the speed of reaction (i.e., onset latency) for infrared improves with both the duration and area, just as it does with power density. In other words, onset latency is related to spatial and temporal summation. It will be especially interesting to learn how microwaves behave in this respect, both as regards onset and offset latencies. Casual measurements of onset latency by Justesen, et al. (1982) came to about 3.5-6.0 sec, about an order of magnitude longer than onset latencies shown in Figure 6. In Chapter 10 of this volume D. R. Justesen explores the unfavorable implications of these long latencies in the learning of escape behavior by murine organisms exposed to microwave radiation. The long offset latencies observed by Hendler, Hardy, and Murgatroyd (1963) and by Justesen, et al. (1982) are also of interest (a kind of "afterglow" that can last up to at least 15 sec). In contrast, infrared sensations extinguish quite abruptly when stimulation ceases.

Although it is at present impossible to say much about thermal sensations aroused by microwaves, it is doubtless expedient that any future psychophysical programs of studies be guided by past experience with more conventional means of thermal stimulation. Only then will we be able to come to grips with the complexity of the problem and to avoid simplistic generalizations from limited kinds of testing.

#### ACKNOWLEDGMENT

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